Lithography light source challenges for Double Patterning and EUVL

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ABSTRACT

The need for improved lithography resolution has driven the development of light sources with ever shorter wavelength. Excimer lasers have extended the exposure wavelength down to 193nm. Further resolution extension will require the introduction of Extreme UV (EUV) light source technology at 13.5nm. The traditional light source driver at each technology node has been higher power which enables increased productivity. More recently, improved light source stability, driven by tighter CD and overlay budgets for Double Patterning processes, has become more important and developments in this area will be described. The leading challenge for insertion of EUVL is source power and lifetime, which are both necessary to ensure cost effective operation. The first Laser Produced Plasma (LPP) production source using a high power CO_2 laser and tin droplet targets is described. High conversion efficiency has enabled high EUV power performance. Continuous operation up to 18 hours, with stable power output, has been demonstrated. High collection efficiency is obtained using a large (5sr) multilayer mirror collector optic. The first integrated source will be delivered to support scanners for process development and insertion of EUVL at the 22nm node. A roadmap for future generations of LPP sources with scalable power will be outlined.

Keywords: Excimer, Laser, Double Patterning, EUVL, LPP

1. INTRODUCTION

Deep-UV wavelength excimer laser light sources have driven lithography resolution to about 60nm half-pitch for dry exposures and about 40nm for 193nm immersion exposures. Further resolution extendibility requires Double Patterning techniques or the introduction of Extreme UV (EUV) lithography at 13.5nm. The traditional laser light source drivers at each technology node have been higher power and smaller bandwidth. High power enables increased productivity and lower cost per layer as scanner stage speed increases. Small bandwidth minimizes contrast degradation due to chromatic aberration in the projection lens, which becomes more challenging at higher numerical aperture (NA). Since NA has reached the maximum for CaF_2 optics, and water-based immersion Double Patterning technology has been adopted for further improvement in resolution, there has been less demand for reduced bandwidth and instead a focus on greater stability of bandwidth and other light source operating parameters. This is driven by the tighter CD and overlay budgets needed in Double Patterning processes.

Higher power lasers have recently been introduced to mitigate the productivity loss associated with Double Patterning. However, increased power though the laser and scanner optics leads to higher thermal loads which can impact Cost of Ownership and performance stability. New materials and control methods have been developed to compensate for these effects. This paper will present results from the XLR 600i laser which is a 90W dual-chamber system that addresses these issues using a unique, recirculating ring architecture.

EUVL has been under development for some time and a few prototype full-field exposure tools have been delivered. The top challenges for insertion of EUVL into production are source power and lifetime, resist resolution and sensitivity and mask defect density. The cost of ownership of the technology, in comparison to alternative technologies, is also a key consideration for adoption. Currently, the leading technology challenge is related to the light source. The source must reliably deliver high power, for high scanner productivity, and long component lifetime, both of which are necessary to ensure cost effective operation. This paper will review recent progress on the development of a Laser Produced Plasma (LPP) EUV source. The integration status of the first LPP production source will be discussed. Results of progress on power output and debris mitigation will be presented. A roadmap for future generations of LPP sources with scalable power will be outlined.

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2. LASER LIGHT SOURCES

Laser light sources were introduced to provide high power within the narrow spectral bandwidth required for imaging with single-material (fused silica) projection lenses having significant chromatic aberration. For many years, both power and bandwidth requirements could be met using single chamber excimer lasers. However, about five years ago MOPA (Master-Oscillator-Power-Amplifier) dual chamber lasers were introduced for ArF lithography in order to separate the line narrowing and power generation functions of the laser into separate chambers and provide continued power scaling while simultaneously reducing spectral bandwidth. This concept has proved to be very successful and has allowed power scaling up to 60W supporting significant improvements in scanner productivity. The MOPA design was enhanced recently using a regenerative power amplifier to provide further extendibility in both power and system stability [1]. The XLR series of lasers was designed with 90W power output capability to support future improvements in stage scanning speed and for exposure of high dose resist layers. The XLR architecture also offers significant improvements in pulse energy stability and dose control, bandwidth stability and wavelength stability which provide the potential for improvements in CD control and productivity [2]. Recent developments in control algorithm technology have enabled even further improvements in energy stability and current XLR lasers show dose stability performance about 3x better than the previous generation dual-chamber lasers, shown in Figure 1, providing both improved CD control and productivity.

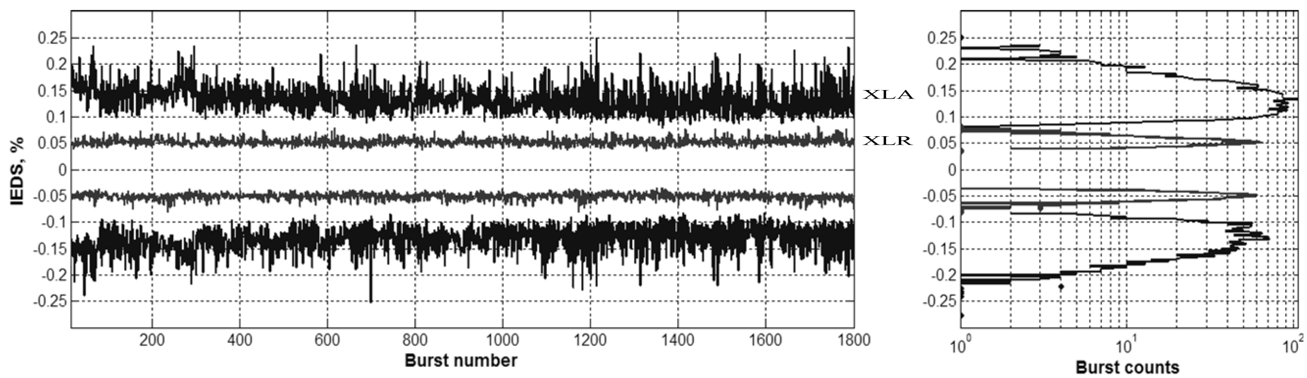

Fig. 1. Integrated energy dose stability for XLA 300 and XLR 500 lasers

Requirements for laser bandwidth have shifted from reducing mean bandwidth to improving bandwidth stability. Many process layers use complex Optical Proximity Correction (OPC) models which rely on stable image contrast and can be affected by bandwidth variation. Bandwidth stabilization now requires multiple control methods, including fast differential discharge timing control to compensate for short timescale thermal effects, improved gas control algorithms which minimize bandwidth changes due to gas aging within a gas fill lifetime, and optical methods to compensate for long term drift during module aging. Optical adjustment can also be used to provide initial matching of system to system performance. Recent matching and stabilization data is shown in Figure 2. As CD control budgets become tighter, the requirements for accurate mask OPC become more stringent and require laser bandwidth to be considered in the OPC models. This leads to significantly increased computation time unless new spectral approximation methods are developed to optimize the trade-off between speed and accuracy [3]. Such techniques are particularly valuable for 2D and large area simulations, and also for simulations requiring physical resist models or rigorous EM computation.

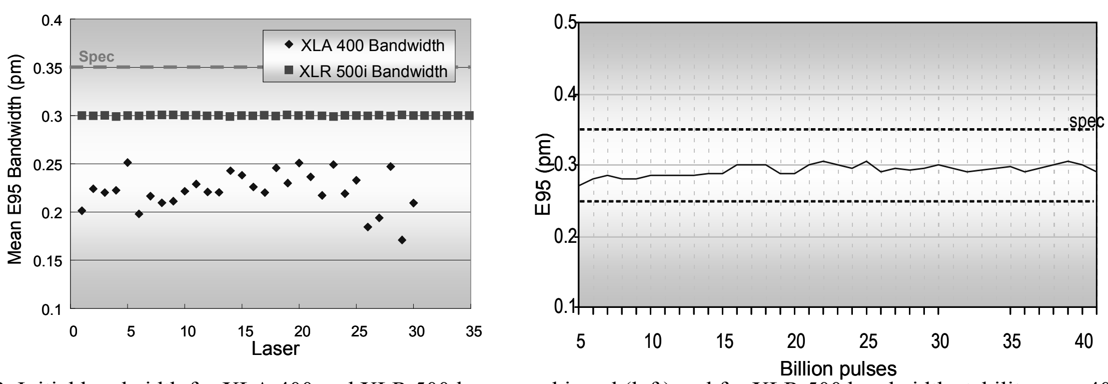

Fig. 2. Initial bandwidth for XLA 400 and XLR 500 lasers as shipped (left) and for XLR 500 bandwidth stability over 40Bp (right)

The new XLR laser architecture also addresses Cost of Ownership through a reduction in both peak spatial and temporal energy density within the beam path, as shown in Figure 3. Together with achievements in new materials durability, this provides longer lifetime for laser components and more stable optical performance.

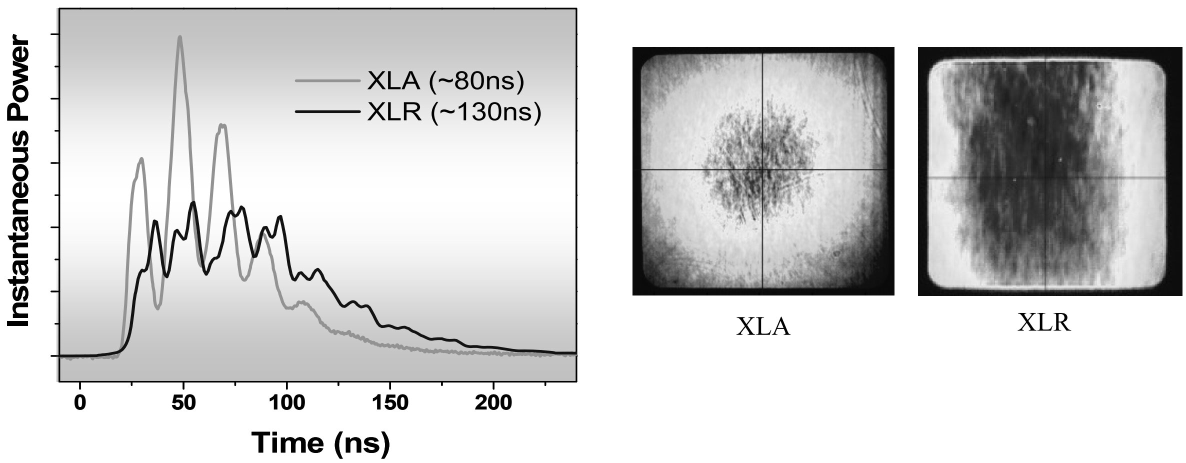

Fig. 3. Temporal peak energy density for XLA and XLR lasers (left), and Spatial peak energy density for XLA and XLR lasers (right).

3. LPP EUV LIGHT SOURCES

3.1 Background

Source power and lifetime have been ranked as the leading challenges for EUVL development for the last three years. The use of reflective optics in EUVL exposure tools leads to low optical transmission and requires high source power in order to allow the scanner to deliver the high throughput needed to provide competitive Cost of Ownership. The goals for power output have also increased due to the difficulty in obtaining acceptable resist resolution and Line Edge Roughness (LER) performance at sufficient levels of sensitivity. The other requirement for source performance is the need to ensure high power output over long periods of time, which also impacts Cost of Ownership. This requirement primarily relates to maintaining high collection efficiency by preventing reflectivity degradation of the collector optics.

Early EUVL exposure systems were delivered with DPP (Discharge Produced Plasma) sources. These sources are suitable for low power output but have significant scaling challenges to reach the power levels needed for cost effective operation in High Volume Manufacturing. They also have issues with inefficient collection of the output light due to the large plasma size, geometrical constraints and debris mitigation challenges. The clear leader for high power, production EUV sources is Laser Produced Plasma (LPP) technology. This source architecture provides the key advantages of high conversion efficiency and high collection efficiency with intrinsic scalability of the output power to future High Volume Manufacturing levels.

LPP sources use a drive laser to heat a target material forming a high-temperature plasma which emits at the EUV wavelength of 13.5nm. Evaluation of different combinations of drive laser wavelength and target material has shown that the optimum combination is a CO_2 laser, running at 10.6um wavelength, and tin target material. This produces the highest conversion efficiency, from the total laser input energy to in-band EUV output energy. One of the key advantages of LPP sources is the possibility of collecting a high proportion of the isotropically emitted energy and directing it to the Intermediate Focus (IF) position, which is the interface between the source and the exposure system. The LPP architecture allows high collection efficiency due to the small plasma size and large geometric collection angle that is possible because the plasma is well isolated from any chamber components.

3.2 System Architecture

Cymer's current LPP system chamber architecture is shown in Figure 4. Tin droplets are produced by a droplet generator in the wall of the vessel. Light from the CO_2 laser enters the chamber through a central aperture in the collector mirror. The laser beam is focused and steered using closed loop feedback from the droplet targeting cameras to precisely target the stream of tin droplets. A plasma is formed by the interaction of the laser pulses and tin droplets at one focus of the elliptical mirror. Light is collected and refocused to the second focus of the mirror, which is the Intermediate Focus position. The high power pulsed CO_2 laser is based on production-proven commercial technology, capable of delivering 12kW of output power at 50kHz, and scalable to higher power for future generations of EUV sources.

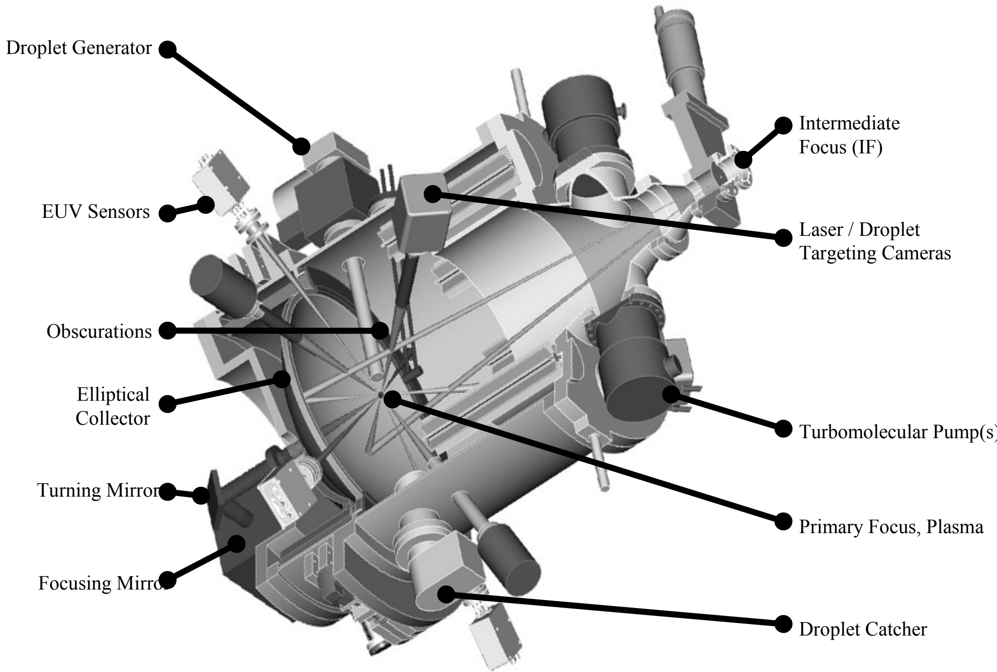

Fig. 4. Cymer LPP source plasma chamber architecture.

The system chamber will be integrated directly with the scanner body and requires much closer design integration between the source and scanner than for excimer laser light sources. The laser and support electronics will be installed in the sub-fab and the output laser beam will be directed through the fab floor to the plasma chamber. The first two production sources have been assembled and are operational. One of these is shown in Figure 5.

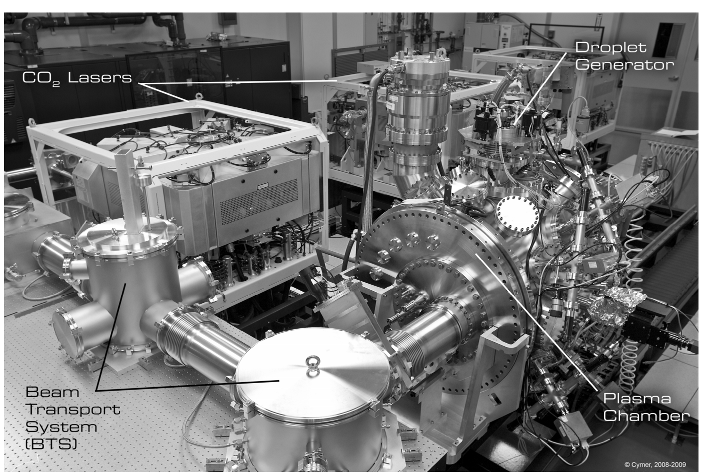

Fig. 5. First integrated production LPP source.

3.3 Collection Efficiency

High collection efficiency is achieved using a large, high reflectivity, high collection angle ellipsoidal mirror. The mirror comprises many silicon-molybdenum multilayers, similar to the scanner optics mirrors, which reflect a small band around the target wavelength. Two key differences for the collector mirror are the use of a graded multilayer spacing from center to edge of the mirror, to compensate for changing incidence angles, and a novel multilayer design to resist interdiffusion (and loss of reflectivity) at the high temperatures likely to be experienced in the source chamber [5]. Sub-aperture (320mm diameter) mirrors have been fabricated with low surface roughness and when coated show excellent center to edge reflectivity uniformity. The production systems will use larger mirrors of about 600mm diameter, with 5 steradian collection angle. The first 5sr mirrors are shown in Figure 6.

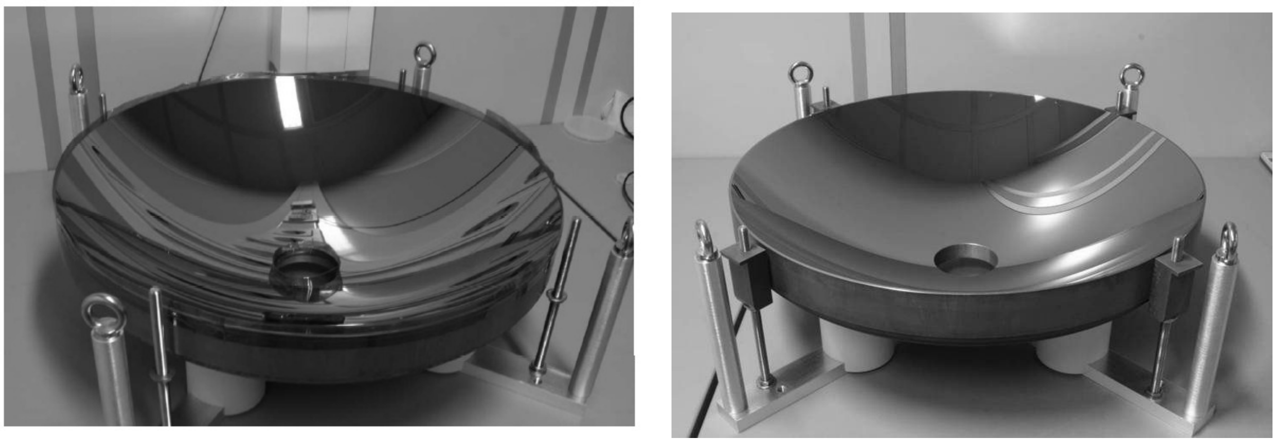

Fig. 6. First two 5 steradian collector mirrors after polishing (left) and coating (right).

A key challenge is to maintain the high collection efficiency, and stable power output, over long periods of time, in order to meet Cost of Ownership targets. The proximity of the collector optic to the high temperature plasma exposes it to high energy ions, neutral atoms and other debris which can damage the coating and reduce reflectivity. The three main degradation mechanisms are deposition of tin particle debris from the droplets, erosion of the mirror by high energy ions and neutral atoms and deposition of tin vapor. The use of small droplets is arguably the most important debris mitigation technique and is necessary to reduce the load on the individual debris mitigation subsystems responsible for eliminating each degradation mechanism. Droplet sizes as small as 30μm diameter have been demonstrated for extended run times and are now routinely used in LPP systems for integrated testing. Droplets of this size provide the added advantage of reducing the annual tin consumption, which minimizes tin material costs.

One debris mitigation subsystem addresses multilayer erosion by significantly reducing the ion flux incident at the mirror surface by up to four orders of magnitude, and the ion energy by about an order of magnitude. Erosion can also be addressed by adding sacrificial multilayers during the coating step of collector fabrication. A second debris mitigation subsystem eliminates tin deposition, which is critical because only about a 1nm layer of tin results in unacceptable reflectivity loss. When all mitigation schemes are active, it has recently been shown that the source can be operated for 8 hours without degradation of collection efficiency, as shown in Figure 7.

3.4 Power

The initial power requirement for EUV pilot production sources is about 100W (in-band at IF). In-band conversion efficiency of 3%, using an 11kW laser, is required to achieve this power level and was demonstrated using droplet targets in 2007 [4]. Stable power output requires highly repeatable droplet position and spacing, with a closed loop laser targeting control system which ensures that each laser pulse is optimally focused and accurately targeted on the corresponding droplet. Currently, thermal control of the beam delivery and focusing optics is under continual improvement to extend continuous operation performance to higher power levels. Initial firing patterns using 1msec bursts and 8% duty cycle demonstrated 100W power output. The firing pattern has recently been extended to 400msec bursts and 80% duty cycle, which is typical of scanner operating conditions. Under these conditions, 20W exposure power output has been achieved for up to18 hours of continuous running time, and is shown in Figure 8. For these results, power is measured by an EUV monitor consisting of a photodiode, a 2% bandwidth mirror and Zr foil looking at

the plasma, and calculated at IF using the standard assumptions of 5sr collection, 50% average reflectivity and 90% transmission. A useful source performance metric is total dose per day. As shown in Figure 9, more than one MegaJoule (MJ) was produced during this 18 hour test. One MJ of EUV energy at IF is enough to process approximately 250 wafers of 300mm diameter.

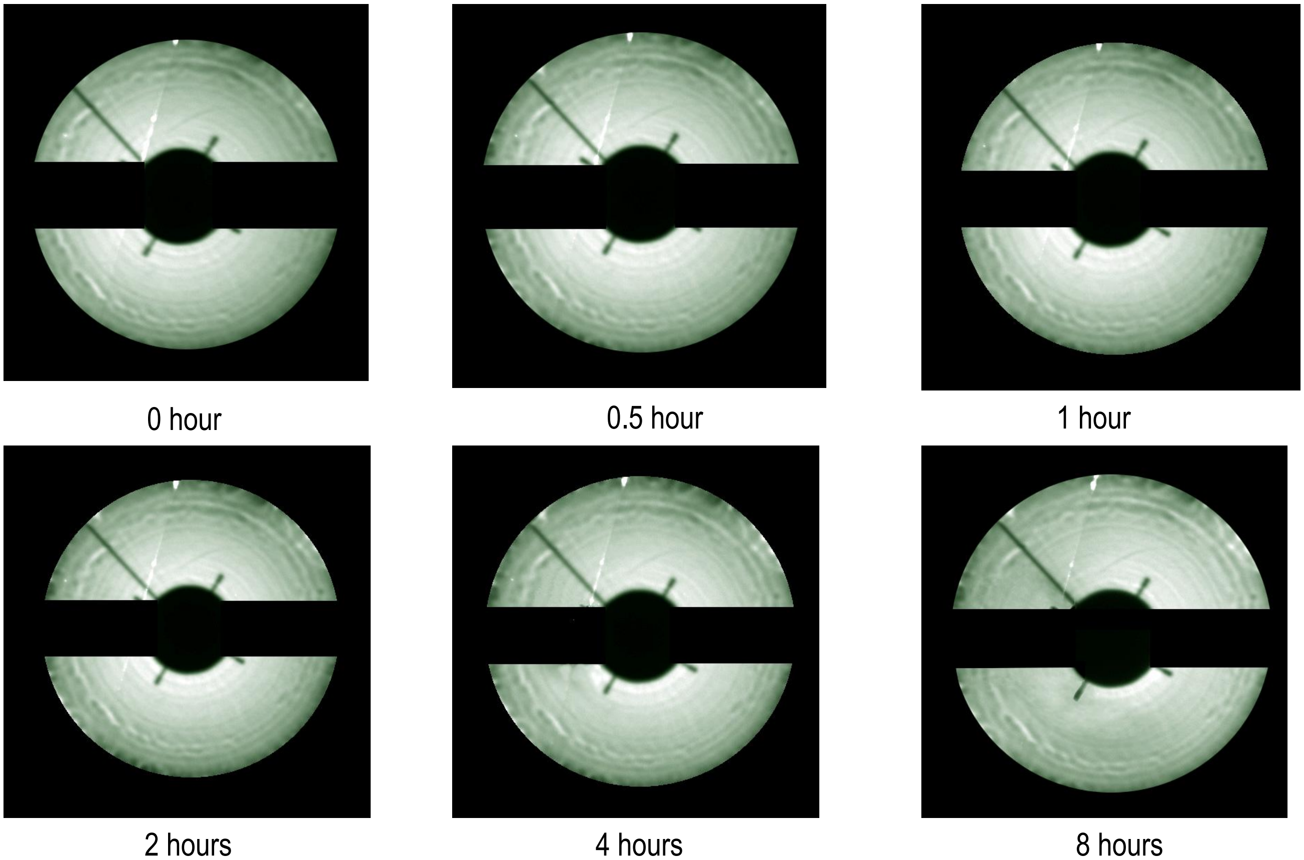

Fig. 7. Fluorescence screen images at IF over 8 hours of operation with active debris mitigation showing no change in reflectivity.

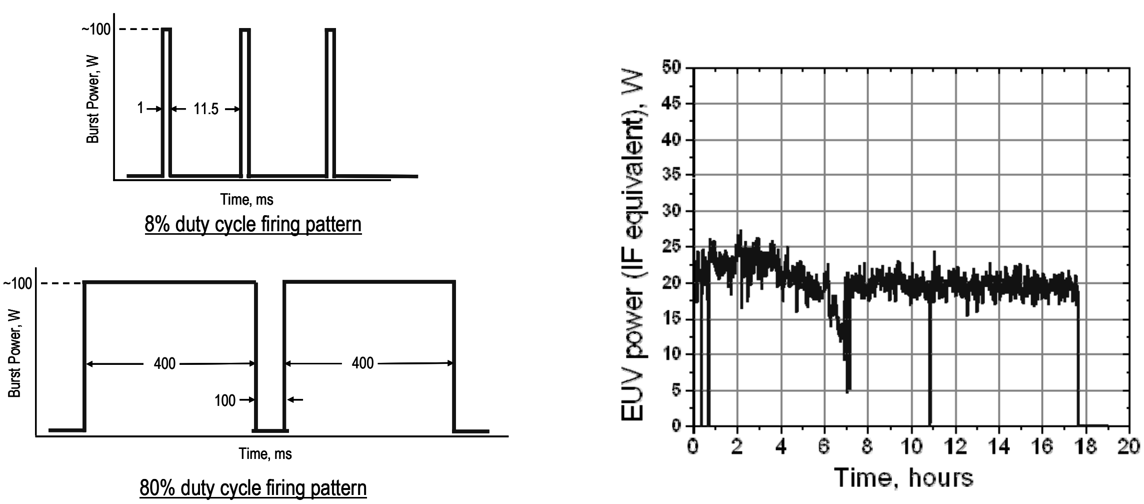

Fig. 8. Demonstrated power output of 20W for up to 18 hours at 80% duty cycle.

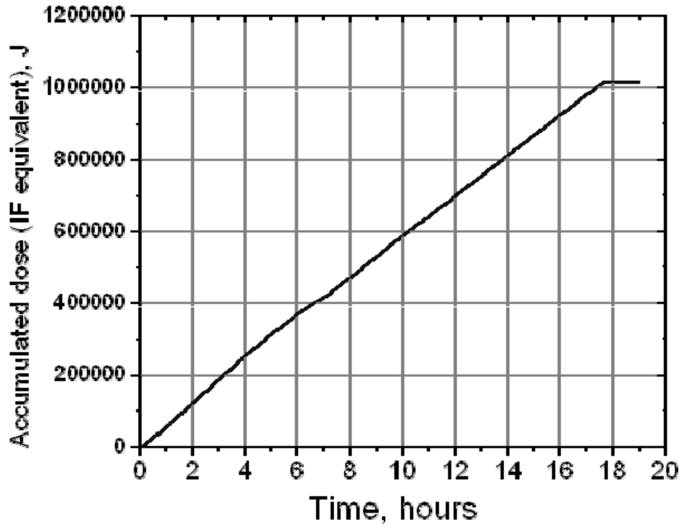

Fig 9. Accumulated dose over 18 hours run time at 20W

3.5 Roadmap

Cymer's LPP source development and product roadmap is closely aligned with the scanner manufacturers' roadmaps, and is shown in Table 1. Several first generation pilot EUV sources are planned to be delivered during 2009. During this time, the technology will continue to be improved before the integrated exposure systems are delivered to chipmakers in 2010 for process development of next generation devices. By the time EUVL is introduced into production, it is expected that the technology will meet all of the requirements of the commercial semiconductor capital equipment industry. Additionally, later systems for high volume production are expected to operate at higher power than these initial pilots. Further development and engineering of EUV sources is planned for many years to come, with progressively higher power and lower cost of operation systems being delivered to support the roadmaps of both the scanner manufacturers and chipmakers through the next several device nodes.

Table. 1. Cymer LPP EUV source power roadmap.

EUV Source Power Roadmap			
	Pilot	HVM I	HVM II
Drive laser power (kW)	**11**	**19**	**>20**
In-band CE (%)	3.0	3.5	4.0
Collection Efficiency (sr)	5	5.2	5.5
Collector Reflectivity (%)	>60	>60	>60
Optical Transmission (%)	80	85	90
Total EUV power at IF (W)	**>100**	**>200**	**>400**

4. CONCLUSIONS

Light source developments have contributed significantly to lithography resolution and productivity improvements. Recent changes to the excimer laser light source architecture have also provided a new level of stability and durability at higher power levels that will be critical for Double Patterning applications. This platform will allow further extendibility until EUVL is ready for manufacturing introduction. There has been significant progress in the development of high efficiency LPP light sources for pilot EUVL exposure tools. The first systems have been integrated and several units will be delivered during 2009. Continuous improvements in power output, collector lifetime and operating time are planned and will enable a roadmap that supports the first two generations of High Volume Manufacturing tools.

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